EXPERIMENTAL RESULTS OF THE IMPACT OF AN ION THRUSTER PLASMA ON MICROWAVE PROPAGATION

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INTRODUCTION

Electric thrusters are being considered for a variety of space missions because of the significant propellant savings that result from the use of high performance, electric propulsion technologies. Propellant mass savings reduces spacecraft launch requirements and increases mission lifetime and payload. The impact of electric thruster plasma plumes on microwave signal propagation however is an important spacecraft integration concern. Arcjets were the first electric thrusters to be considered for operational missions. Ling, et al. [1], studied the effect of arcjet plumes on propagation. Arcjets produce a lightly ionized plume and Ling's analysis predicted that the plume would have a negligible effect on communication.

Plumes from the higher performance ion thrusters being developed exhibit higher ionization levels, plasma temperatures and particle velocities than arcjets. Therefore, there was a need to assess the impact due to these plumes. To address this need, the authors designed and performed a series of experiments to examine propagation effects of plumes. The challenge with these experiments was that they had to be performed in the operational environment of the thruster. Therefore, the experiments were conducted inside a metal chamber which could be depressurized to simulate a near vacuum condition of space. The metal chamber presents a potential large source of error to the propagation measurements due to the corruption of the desired data by multiple wall reflections within the chamber. This chamber effect was minimized by employing a pulsed-continuous wave transmitter and receiver system [2]. This system, based on an HP8510 Network Analyzer, uses external hardware time gating to eliminate the clutter of the spurious reflections. Additionally, high gain antennas were used in the measurements to ensure that minimal amounts of energy were transmitted/received in undesirable directions. A schematic of a basic test is shown in Fig. 1.

The measurements took place in Vacuum Facility 5 of the Electric Propulsion Laboratory at the NASA Glenn Research Center. This facility utilizes a cylindrical, stainless steel, vacuum chamber, which is 18.3 m long and 4.6 m in diameter. For the tests being described here a 30 cm diameter, xenon ion thruster was used. The thruster provided between 500 W and 2.3 kW of operating power. The thruster was mounted on a stand along the axis of the chamber near one of its ends as shown in Fig. 1 and could be moved axially.

DIRECT PATH MEASUREMENT

In the direct path measurement, a transmit and a receive horn antenna was mounted on the sidewall on either side of the plume centerline. The horns were separated by about 4 m and the propagation direction was normal to the axis of the plume. The transmit pulse modulator provided nanosecond wide bursts, which were captured by a properly controlled, receive switch. Pulse timing and frequency were adjusted to ensure that only the test signal was received and all wall reflections were gated out. Received signal amplitude and phase was measured as a function of frequency and compared relative to a measurement taken with the thruster off. Data was taken from 6.5 to 18 GHz at 8 MHz intervals for various thruster power levels at varying distances from the thruster exit plane. Measurements were taken at four power levels of 0.5, 1.0, 1.5, and 2.3 kW for distances of 0.5 and 1.5 m.

Fig. 2 and Fig. 3 show the results of the measurements. The attenuation effects are very small with a trend of decreasing attenuation with increased frequency. Attenuation increases as the operating power, and hence, as the plume density increases. Phase shift also decreases with increased frequency and increases with increased operating power. The observed effect diminishes at distances far from the plume exit plane.

LINEAR PROBE MEASUREMENT

Since a phase shift was observed in the previous measurements it was postulated that a large antenna, with a plume in its near field, would experience a non-constant phase shift across the aperture. This near-field phase distortion, if appreciable, could cause an antenna beam pointing error. Ling's analytical study [1] has demonstrated such an effect for an arcjet thruster by using ray tracing. Whether such a phase gradient could be detected for ion thrusters of the above power range needed to be resolved. To accomplish this objective, a near field measurement of an electrically large antenna was required inside the chamber in the presence of the plume.

For these measurements, the tank configuration of Fig. 4 was used. The transmit antenna was an offset fed parabolic reflector with a nominal 55 cm diameter operating at 9.67 GHz. The receive antenna was a wide beam, broadband horn which was mounted to a linear translator. The translator was oriented to be parallel with the axis of the plume and the height was set to probe along the horizontal centerline of the reflector. The total scan distance was 76 cm, where the center of the scan coincided with center of the projected aperture of the reflector antenna. The center of the reflector antenna aperture and the center of the translator were set to be 1.0 m from the plume exit plane. The axis of the plume was 1.8 m from the transmit antenna and 1.7 m from the probe antenna thus making this a valid near field measurement. For a given thruster power level, the amplitude and phase of the reflector near-field was measured at every 0.5 cm for the entire scan distance with the broadband horn and compared relative to its value at the no plume case with the thruster off.

Fig. 5 through Fig. 7 show the results for 0.54, 1.37, and 2.3 kW. In general, no tapering in the phase shift can be seen at any power level. Although the attenuation and phase shift fluctuate, both effects appear to be insignificant.

CONCLUSION

The primary effect of an ion thruster plume is a change in the phase of the signal that travels through the plume volume. Even for the worst cases tested, this change of phase is very small (8 degrees maximum) and most likely will not have an impact on spacecraft communications for the range of thruster power levels considered. The plume also causes attenuation of the signal (less than 0.1 dB) but the levels are such that it is also insignificant. The near field scan of the reflector antenna indicates that the plume would not distort the far field pattern of the antenna under the conditions tested. A more detailed description of the experiments can be found in [2]–[4].

REFERENCES

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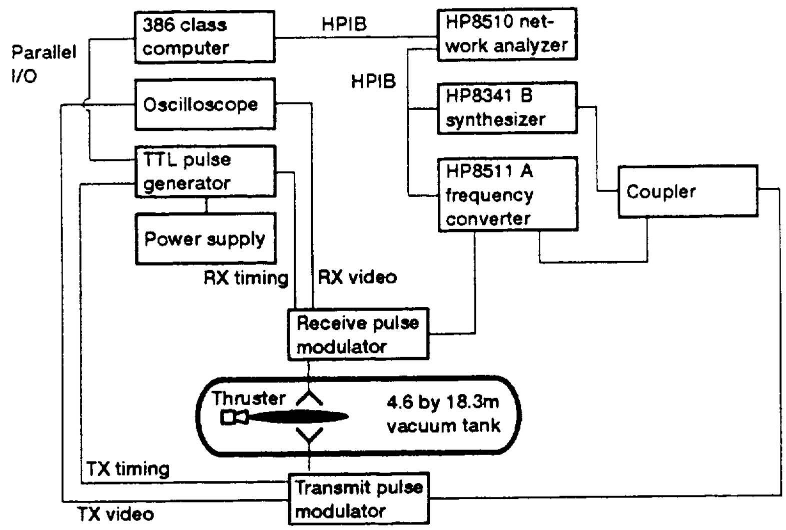

Fig. 1. Equipment configuration for the measurements.

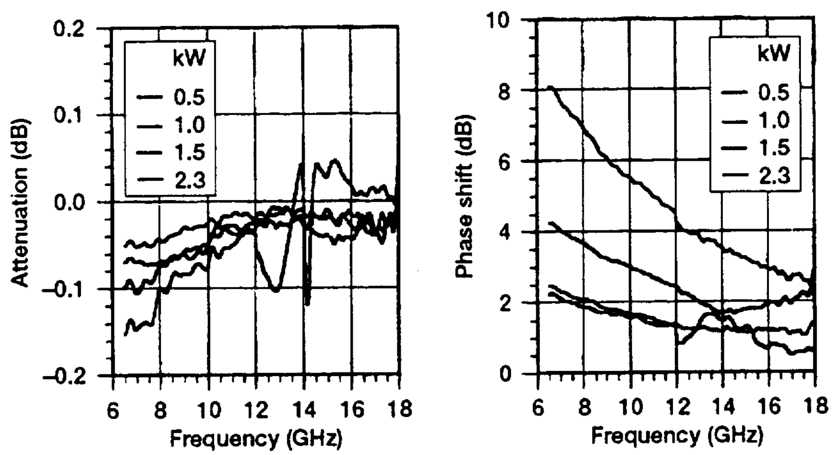

Fig. 2. Signal attenuation and phase shift at 0.5 m from the exit plane.

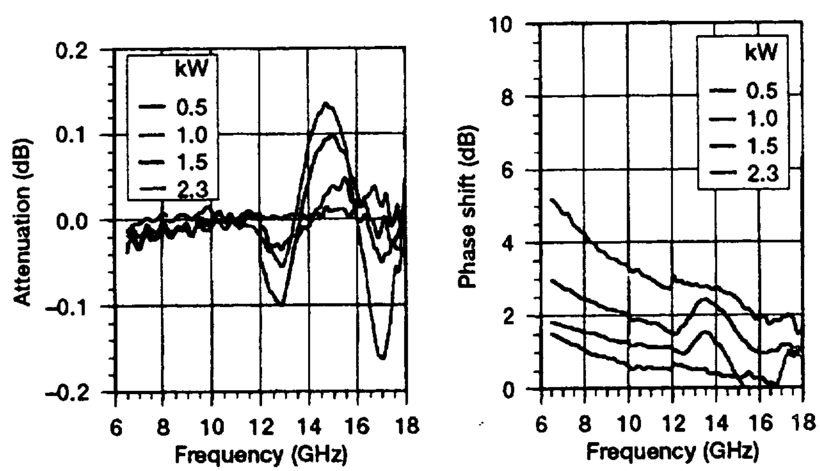

Fig. 3. Signal attenuation and phase shift at 1.5 m from the exit plane.

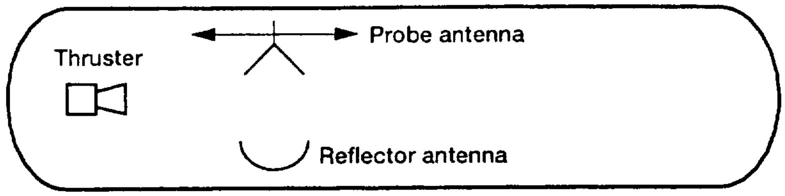

Fig. 4. Schematic of vacuum tank for probe measurements.

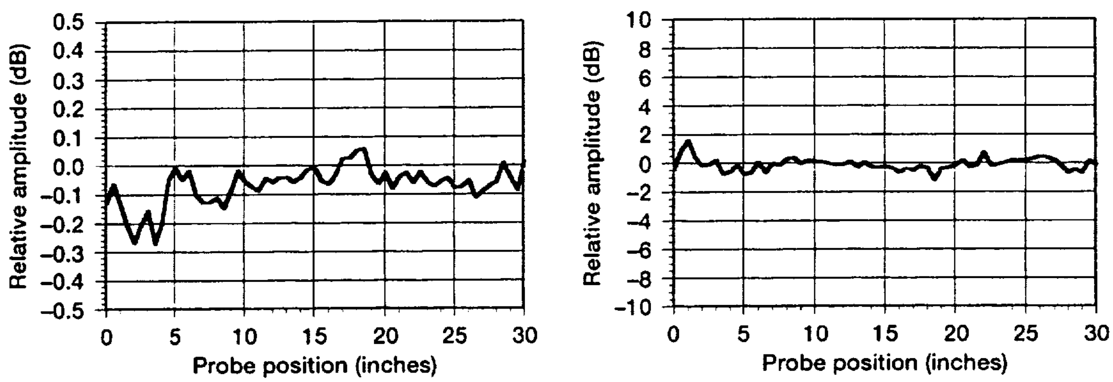

Fig. 5. Attenuation and phase shift as a function of axial position for the thruster at 0.54 kW.

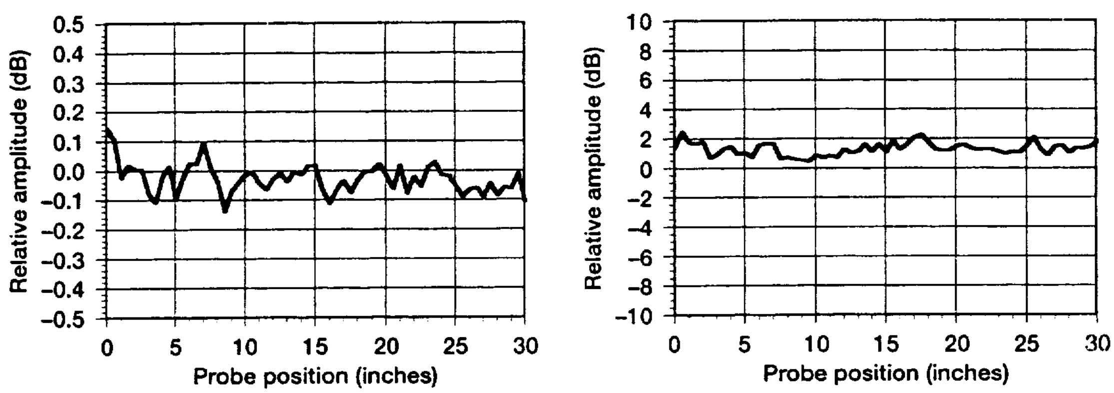

Fig. 6. Attenuation and phase shift as a function of axial position for the thruster at 1.37 kW.

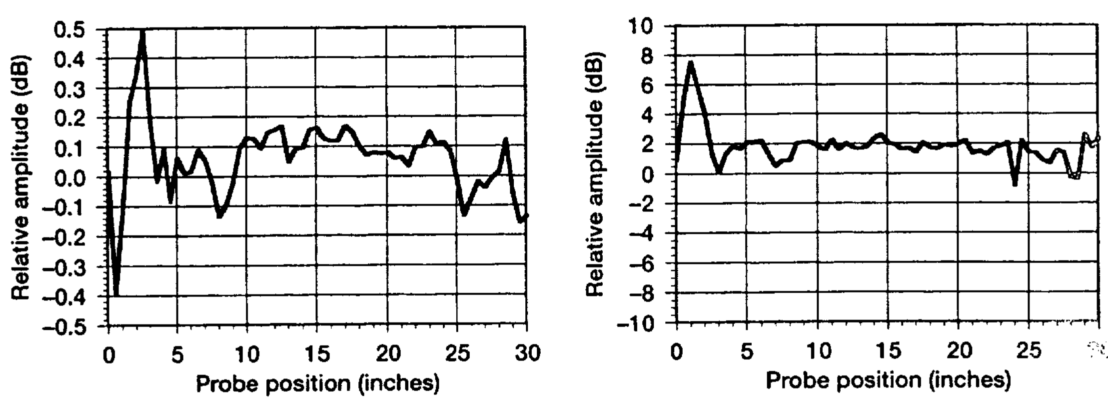

Fig. 7. Attenuation and phase shift as a function of axial position for the thruster at 2.3 kW.